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General File

March 6, 2000

Mr. George Robin
Groundwater Office of the Environmental Protection Agency Region IX
75 Hawthorne Street
San Francisco, California 94105

Dear Mr. Robin:

SUBJECT: Transmittal of report

As requested in the technical review letter of February 23, 2000, enclosed is the following technical report:

> *Summary of Tulare Formation Groundwater Conditions along the South Flank of Naval Petroleum Reserve No. 1, Elk Hills, Kern County, California*, by Mr. Michael V. Phillips of Research Management Consultants, Inc., December 1992

Please call if you have any questions.

Sincerely,

Donna M. Thompson

Donna M. Thompson

Enclosure

cc: Mr. Dennis Champion, Elk Hills Power, LLC
Mr. Terry Schroepfer, Quad Knopf
Ms. Laura Tom Bose, Environmental Protection Agency

SUMMARY OF TULARE FORMATION GROUNDWATER CONDITIONS ALONG THE SOUTH FLANK OF NAVAL PETROLEUM RESERVE NO. 1 ELK HILLS, KERN COUNTY, CALIFORNIA

Prepared by:	Michael V. Phillips Environmental Specialist Research Management Consultants, Inc. Tupman, California
Prepared for:	U.S. Department of Energy Naval Petroleum Reserves in California Tupman, California
With Contributions by:	Tom A. Mele Geologist Bechtel Petroleum Operations, Inc. Tupman, California

DECEMBER 1992

RMCI

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Research Management Consultants, Inc.

MEMORANDUM

Date: December 11, 1992
To: Wayne Kauffman
From: Mike Phillips MP
Subject: Technical Report on South Flank Groundwater Conditions

Attached is the revised technical report which discusses groundwater conditions along the south flank of NPR-1. This report on groundwater conditions supplements the technical report prepared by Mark Milliken on the geology of the south flank NPR-1 area. Originally, this material was to be included in Mark Milliken's report. However, as our investigation progressed, it became apparent that the subject matter would be better presented in two separate reports, instead of trying to consolidate two different sets of data and writing styles into one report.

If you have questions on the material presented in the report, please contact me.

Attachment

cc: (w/o Attachment)
W. Gautreaux, RMCI
K. Meeks, DOE

cc: (w/ Attachment)
M. Fishurn, DOE
M. Milliken, DOE
J. Killen, DOE
G. Walker, DOE
C. Valentino, BPOI
T. Mele, BPOI
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DECEMBER 1992

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Management Summary

An investigation of groundwater conditions was undertaken in an effort to identify changes in Tulare Formation conditions on the south flank area of Naval Petroleum Reserve No. 1 (NPR-1). Such changes could indicate effects attributable to NPR-1's source water withdrawals from and produced wastewater injection into the Tulare Formation.

Baseline south flank NPR-1 water levels were determined and compared against current water levels. Little change was noted over an 11 to 13-year period despite high rates of withdrawal and disposal injection in the vicinity. Groundwater quality monitoring data for the Tulare Formation of the south flank NPR-1 area were also compared against baseline conditions prior to any withdrawals or disposal injection. No significant trends over time were observed in groundwater quality monitoring data.

The results of the investigation indicate that source water withdrawal rates are within the safe yield of the Tulare Formation aquifer. Significant declines in water table elevations are not anticipated from continued withdrawal to support oil production at NPR-1. The results of the investigation also indicate that the south flank disposal injection project has been operated substantially in compliance with the requirements of the Underground Injection Control program to protect underground sources of drinking water.

1. Background

The development of the Tulare Formation aquifer along the south flank area was undertaken to supply a source of water for supporting waterflood projects at NPR-1. The Tulare Formation provided a much fresher potential source of groundwater than the deeper oil producing formations at NPR-1. The decision to develop the south flank as a water source area was determined from a series of pilot wells and aquifer pumping tests. The initial effort to test the Tulare Formation for source water supplies occurred along the south flank at oil well 48-9G. This inactive well was recompleted as a Tulare Formation water test well in mid-1978 (WBEC undated). Figure 1-1 shows the locations of all active and abandoned source wells on NPR-1. Figure 1-2 shows the location of the south flank source wells.

In 1979, two pilot wells, 57WS-9G and 57WS-20S, were completed to follow-up on the initial aquifer test results obtained at well 48-9G. The Layne-Western study (1979), was conducted to determine locations of suitable sites on NPR-1 for the development of Tulare Formation water source wells. The criteria for development was an area of the Tulare Formation with suitable characteristics which could provide a reliable supply of 100,000 barrels of water per day (BWPD) over a 10-year period or longer. An area capable of providing approximately 50,000 acre feet of water over a 10-year period was desired. Initially, both the north flank and south flank areas of NPR-1 were considered for development.

Due to unsatisfactory yields obtained at the pilot wells in Section 9G, Layne-Western's report recommended the drilling of water source well 84WS-13B as an additional test well to determine if the south flank area was suitable for long-term extraction. Encouraging results of a long term yield of an estimated 43,000 BWPD were obtained from the aquifer pump tests of well 84WS-13B. This result led to the ultimate development of water source wells along the south flank (WBEC 1981).

2. Tulare Formation Source Water Withdrawal Summary

The volume of groundwater withdrawal from south flank Tulare Formation water source wells has been fairly consistent over a 13-year period, on the order of 30,000 to 60,000 BWPD per well. From 1979 to 1982, two water source wells, 84WS-13B and 82WS-14B provided the Tulare Formation water needed for oil production purposes. Well 86WS-18G was brought on line in 1982 to provide a supplementary/back-up source of supply. Continued heavy withdrawal from these three original source wells led to maintenance and reliability problems over time. This situation led to the addition of three more source wells and the abandonment of one well during the 1990 to 1992 period (DOE 1992a). Average daily source water withdrawal for Fiscal Years 1990, 1991, and 1992 of 127,000, 127,000, and 142,000 BWPD respectively was experienced over this period (BPOI 1990, 1991, 1992a).

NPR-1 SOURCE WATER WELL VICINITY MAP

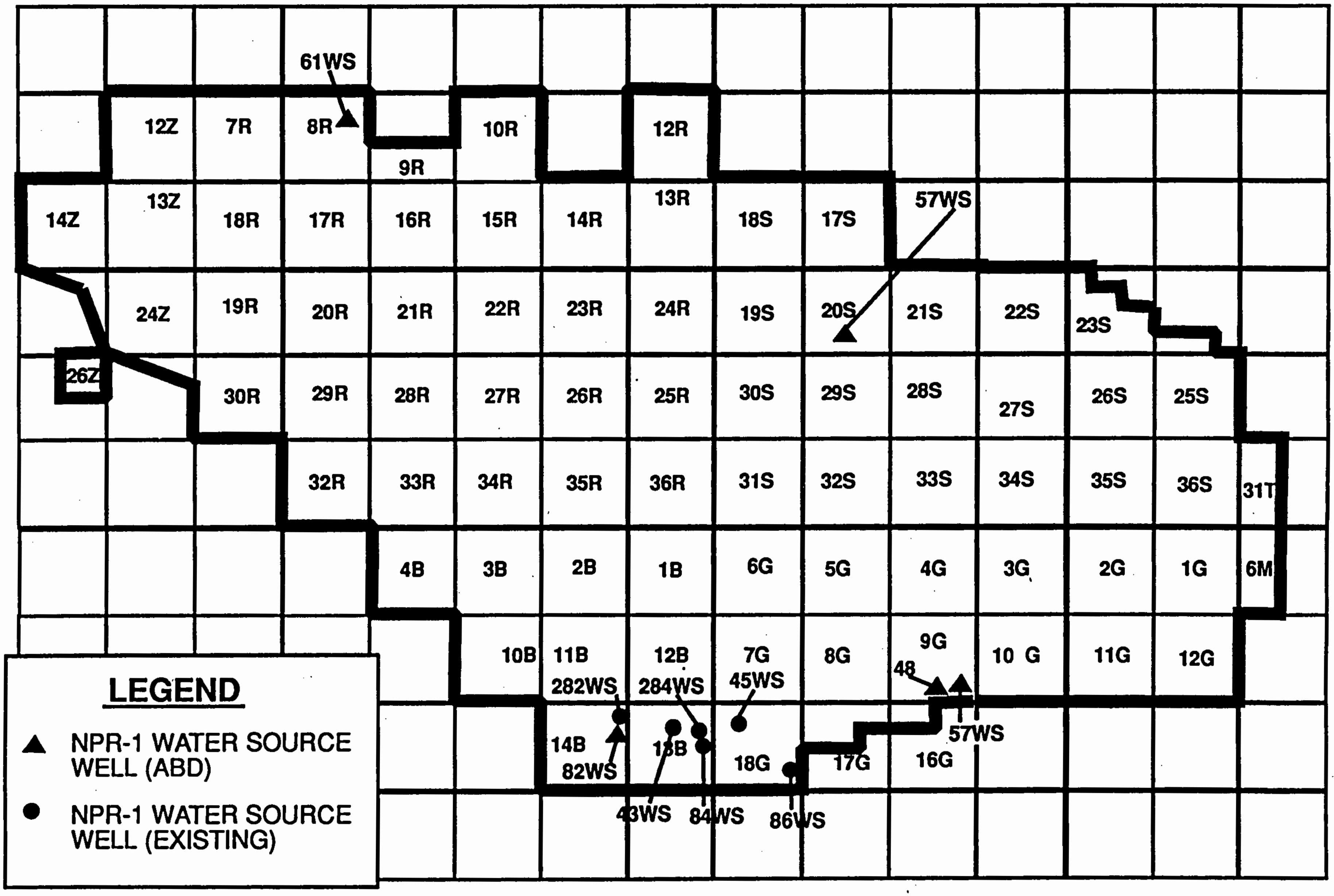


Figure 1-1

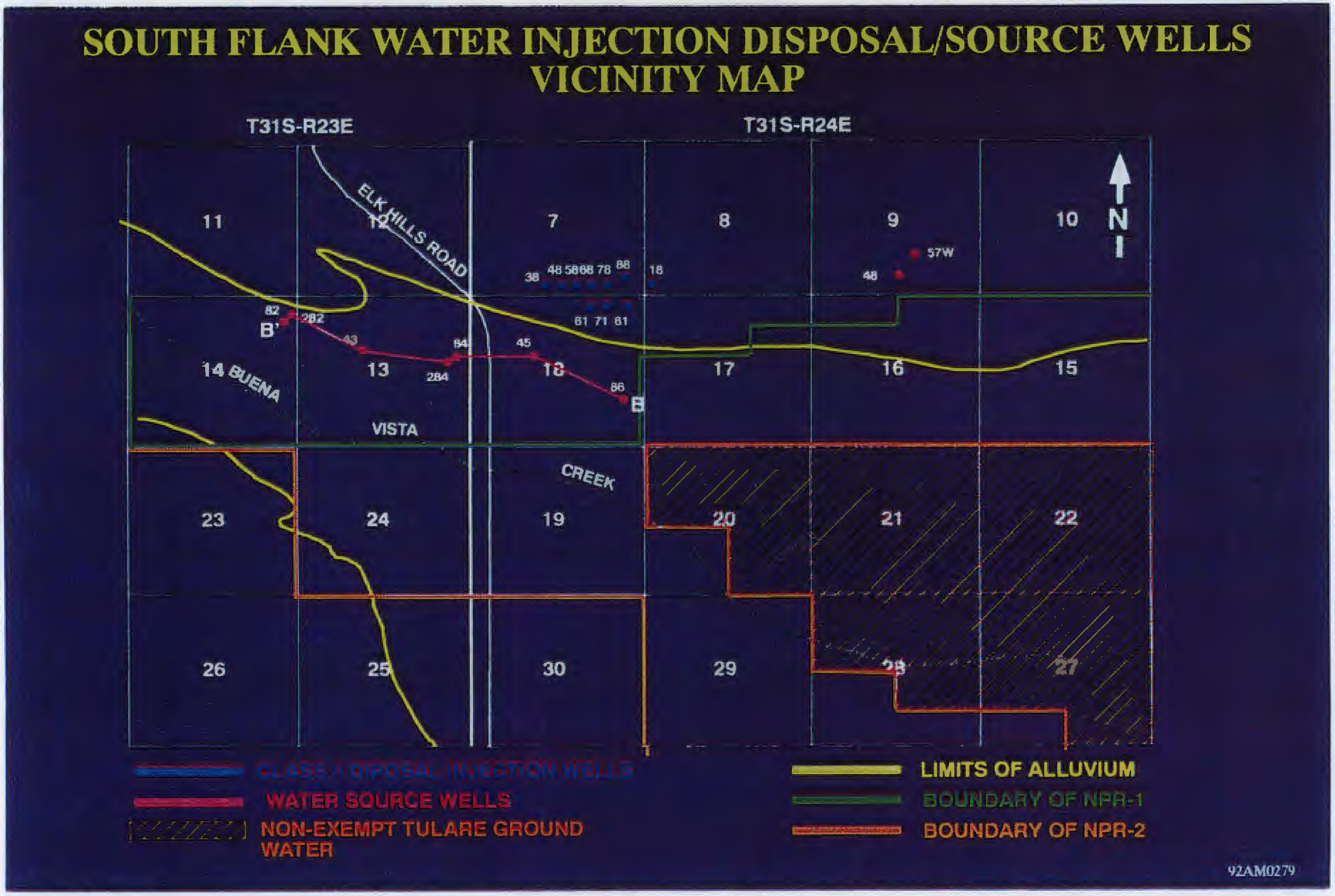

SOUTH FLANK WATER INJECTION DISPOSAL/SOURCE WELLS
VICINITY MAP
T31S-R23E
T31S-R24E
N
ELK HILLS ROAD
BUENA
VISTA
CREEK
B'
B
57W
CLASS II DISPOSAL INJECTION WELLS
WATER SOURCE WELLS
NON-EXEMPT TULARE GROUND WATER
LIMITS OF ALLUVIUM
BOUNDARY OF NPR-1
BOUNDARY OF NPR-2
92AM0279

Figure 1-2

3. Static Water Levels Changes in the Tulare Formation

Examination of data from aquifer pumping tests conducted on each completed well shows there has not been a significant decline in the static water level in the south flank area of the Tulare Formation over a 9 to 11-year period. Table 3-1 provides a listing of these initial static levels, along with the year of the fluid level measurement. Some discussion of these data will illustrate that the water level has remained stable over a long period of time in this area. For example, static water levels in 1979 at well 84WS-13B varied from 242 to 262 feet Mean Sea Level (MSL) over several tests (WBEC 1981). The average water level between the tests was 252 feet MSL. In 1980 at well 82WS-14B, the static water level was 323 feet MSL (WBEC 1981). Eleven years later in 1990, replacement wells 284WS-13B and 282WS-14B, were completed adjacent to source wells 84WS-13B and 282WS-14B. Pumping test results indicated static water levels had not changed appreciably in Sections 13B and 14B over this period despite heavy withdrawal rates (Layne-Western, 1990a, 1990b).

Pumping tests results in Section 18G over a 9 year span also reflect a stable water level. Well 86WS-18G was drilled in 1982 and the static water level was 247 feet MSL (WBEC 1983). In 1991, at well 45WS-18G, the static water level obtained during pump tests was 250 feet MSL, essentially the same level (BPOI 1992b). The lack of a significant lowering of water levels over an area of several miles demonstrates that NPR-1's withdrawal rates from the Tulare Formation during this period are within the safe yield of the aquifer.

Recently obtained data (Owens 1992) from partially completed well 43WS-13B showed a similar lack of decline in static water level. This new well is located approximately midway between source wells 282WS-14B and 284-13B. The static water level measurement at this new well in the summer of 1992 was 284 feet MSL. This level is only 5 feet lower than the level obtained from well 282-14B.

Figure 3-1 provides a structural cross section encompassing the approximate 2 mile width of the source well area. The figure illustrates the major stratigraphic zones along with static water level. The only evident water level response to constant withdrawal has been a slight decrease in level at one location. A decline of 34 feet occurred at the west end of the well field at wells 82WS-14B and 282WS-14B between 1980 and 1990. This decline does not represent a significant drop in the water level, given the steady withdrawal rate of 30,000+ BWPD. The long term productivity of the Tulare Formation aquifer underlying NPR-1 along the south flank should not be affected significantly from continued source water withdrawal to support oil production at NPR-1.

Figure 3-2, a contour map of water table elevations at NPR-1, provides a comparison of the south flank area against regional conditions at Elk Hills. This map was modified from Golder, 1990 by Mele (1992). Along with Golder's data, Maher and others (1975), and Rector (1983), were reviewed together with aquifer pump test data, electric well logs, resistivity logs and neutron density logs from NPR-1 wells. Water levels at particular wells were obtained either from the pump test data or interpreted from the well logs. The map represents the best

TABLE 3-1 South Flank NPR-1 Source Well Static Water Levels

Well Number	Elevation (feet, MSL)	Year
82WS-14B	323	1980
282WS-14B	289	1990
84WS-13B	252	1979
284WS-13B	255	1990
43WS-18G	284	1992
86WS-18G	247	1982
45WS-18G	250	1991
57WS-9G	305	1979
48-9G	273	1978

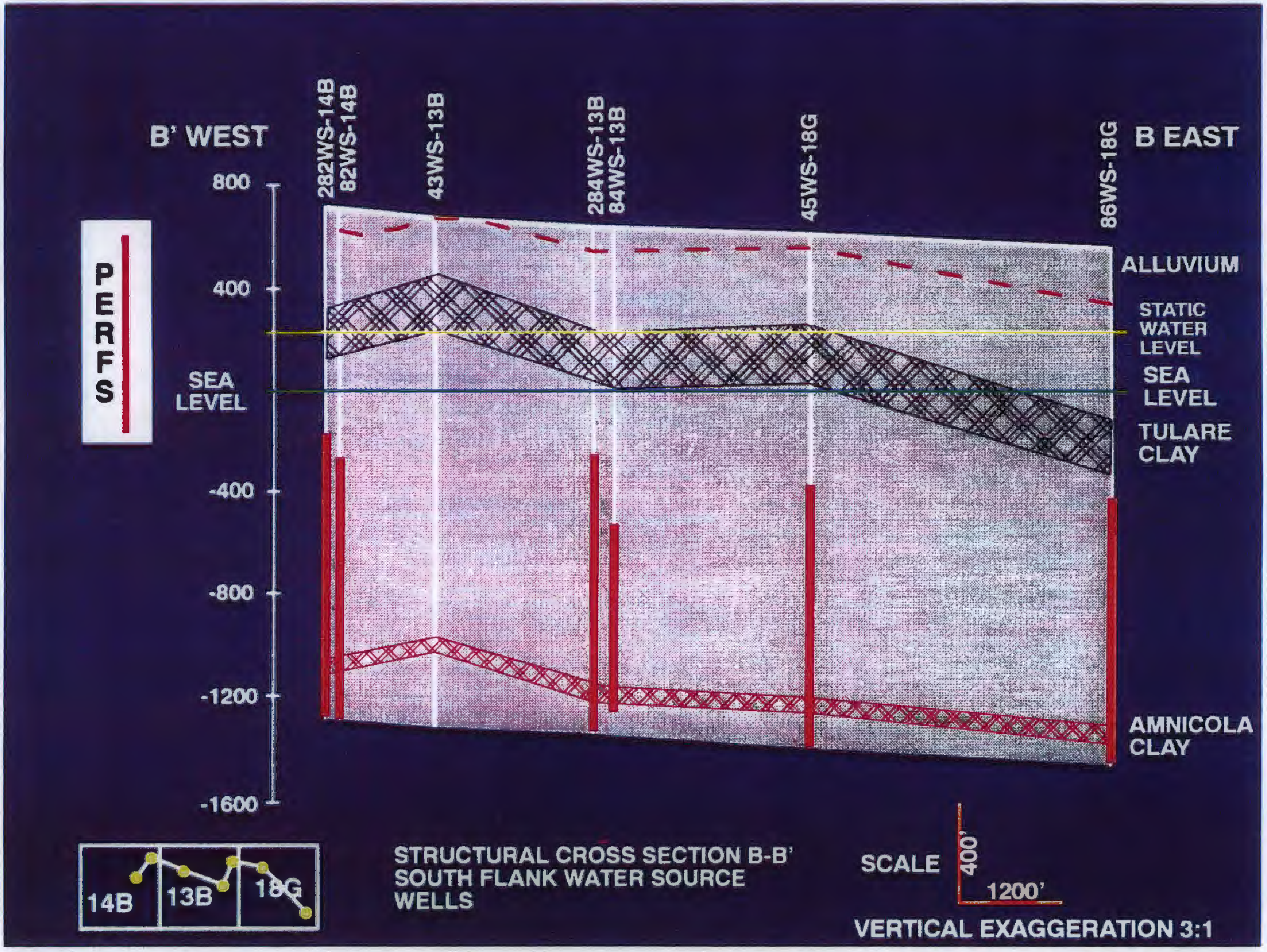
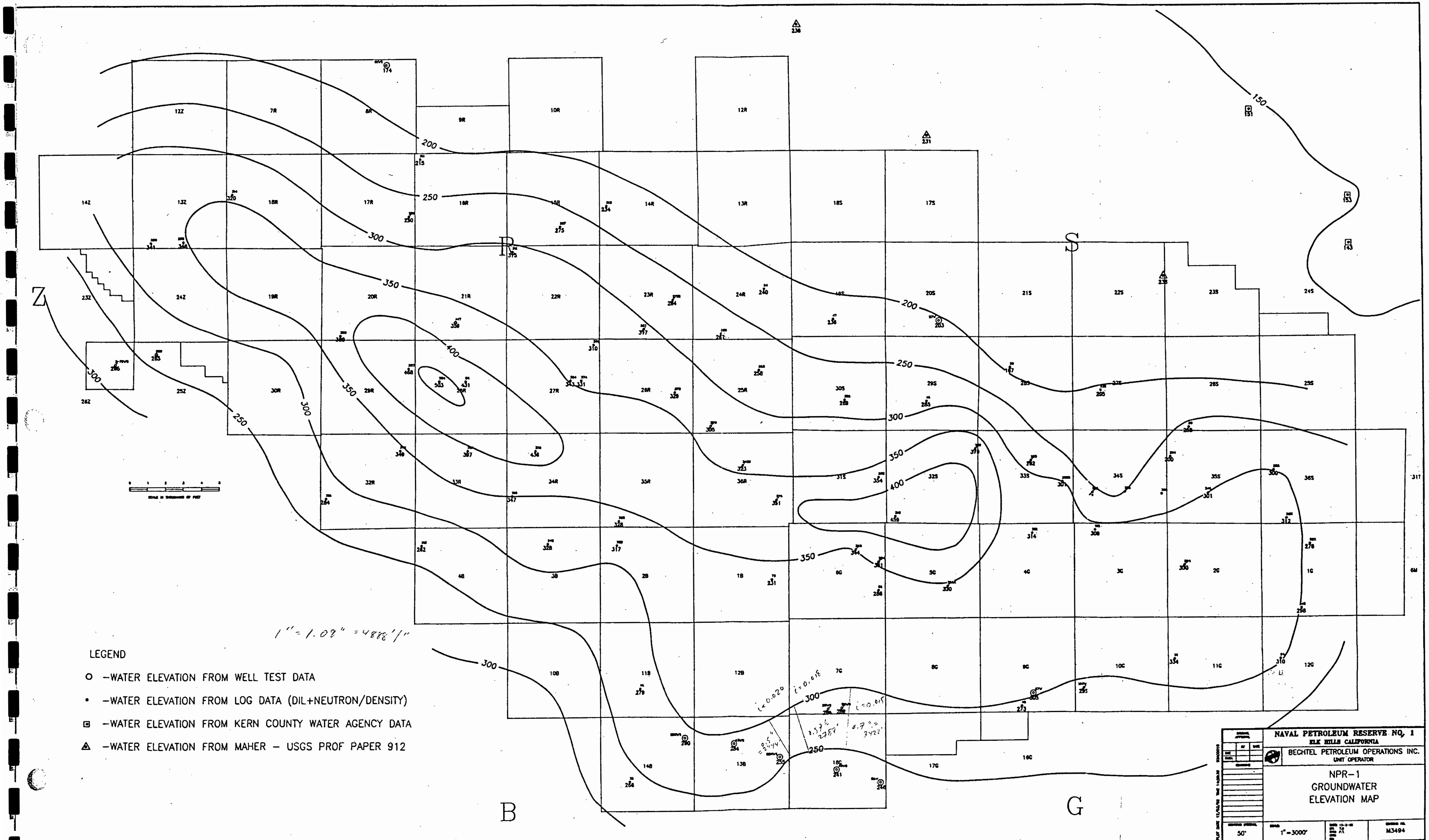

B' WEST
B EAST
282WS-14B
82WS-14B
43WS-13B
284WS-13B
84WS-13B
45WS-18G
86WS-18G
800
400
SEA LEVEL
-400
-800
-1200
-1600
PERFS
ALLUVIUM
STATIC WATER LEVEL
SEA LEVEL
TULARE CLAY
AMNICOLA CLAY
14B
13B
18G
STRUCTURAL CROSS SECTION B-B'
SOUTH FLANK WATER SOURCE
WELLS
SCALE
400'
1200'
VERTICAL EXAGGERATION 3:1

Figure 3-1



150
200
250
300
350
400
Z
R
S
B
G
1" = 1.08" = 4888'/1"
LEGEND
O -WATER ELEVATION FROM WELL TEST DATA
• -WATER ELEVATION FROM LOG DATA (DIL+NEUTRON/DENSITY)
▣ -WATER ELEVATION FROM KERN COUNTY WATER AGENCY DATA
△ -WATER ELEVATION FROM MAHER - USGS PROF PAPER 912
NAVAL PETROLEUM RESERVE NO. 1
ELK HILLS CALIFORNIA
BECHTEL PETROLEUM OPERATIONS INC.
UNIT OPERATOR
NPR-1
GROUNDWATER
ELEVATION MAP
50'
1" = 3000'
M3494

approximation of regional water table elevations at Elk Hills. The data points from which the map was constructed stretch over several decades; therefore, the contours should be considered only as an approximation. The contours of groundwater elevations do, however, compare favorably with those obtained by Rector (1983).

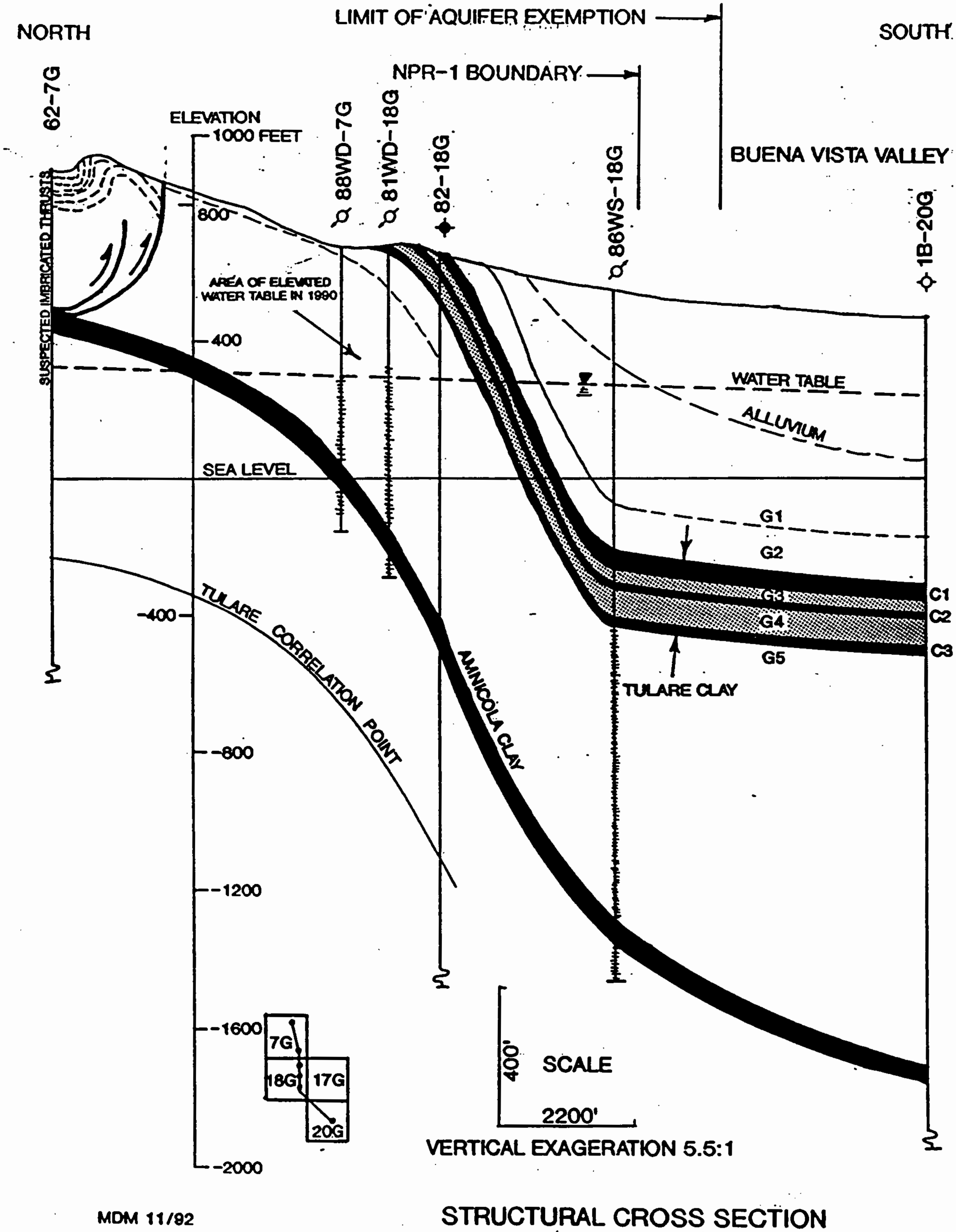
4. Effects of Injection on Static Water Levels in the South Flank of NPR-1

Over the last 10 years between 60,000-100,000 BWPD of produced wastewater have been injected updip from the source wells. This recharge may have had some measure of influence on moderating changes in static water levels in the vicinity. Figure 3-1 illustrates that the source wells are perforated in an interval such that a majority of the groundwater is withdrawn from that zone of the Tulare Formation located between the Tulare clay and the Amnicola clay. This is the same zone into which most of the produced water is disposed of at the injection wells updip. Figure 4-1 illustrates the stratigraphic relationship in the Tulare Formation between the two clay layers at the disposal injection and source wells (Milliken 1992a).

As discussed above, a significant change in static water levels over an 11-year period has not been observed downdip at the water source wells. The baseline static water level, prior to the onset of injection activities, across the vicinity of the injection wells and the source wells was approximately 250± feet MSL. Thus, the recharge influence of produced wastewater injected updip can be shown to have had a small effect on water level changes in the vicinity of the source wells.

The same conclusion cannot be said for static water levels observed at the injection wells. A localized increase in static water levels over a 9-year period was observed by Milliken (1992b) at the wastewater injection wells. Static water levels determined from electric well log interpretation at injection wells 88WD-7G and 81WD-18G were at 246 and 248 feet MSL respectively in 1981. Static water levels determined from electric well logs at wells 38WD-7G and 58WD-7G in 1990 were approximately 30 feet above (284 feet and 282 feet MSL respectively) the 250± foot baseline static water level.

While there is no intervening well log or water level measurement data available from the wastewater injection wells drilled between 1982 and 1990, this increase in static water level at the west end of the injection field most likely represents a groundwater mound. This mound probably extends across the ½ mile width of injection well area. A local increase in water table elevation was believed to be a likely occurrence resulting from injected wastewater disposal. This potential was based upon an investigation of the Tulare Formation's capacity for disposal (WBEC 1985). As shown by Milliken, injected waters are disposed of between two aquicludes, the Tulare clay and Amnicola clay. This stratigraphic relationship does not allow the recharge of the injected water to raise the static water level past the Tulare clay zone. Being constrained by this barrier, the static water levels are evidently increasing locally in the injection field by backing updip against the Amnicola clay layer. Figure 4-1 illustrates this phenomena.



STRUCTURAL CROSS SECTION
SOUTH FLANK NPR-1 TO BUENA VISTA VALLEY

Figure 4-1

5. Summary of Tulare Formation Groundwater Quality at NPR-1

The water quality of Tulare Formation source wells at NPR-1 has been routinely monitored through geochemical analyses of samples obtained from the wells. Data are available for each well from the time the wells were initially drilled to the present, or when they were shut-in or abandoned if no longer active. An independent round of source well water samples was also collected for analysis in mid-1992 (Mele 1992b). The majority of the monitoring data are from the south flank area. Some limited data are available from abandoned wells on the northeast and north flanks.

The potential for degradation of the Tulare Formation's groundwater from the injection of poorer quality produced wastewater updip has been the subject of concern at NPR-1 for some time. Wastewater originating from the deeper formations has a Total Dissolved Solids (TDS) content up to 30,000 parts per million (ppm) and is disposed of by injection into the Tulare Formation at Class II injection wells. Three previous reports investigated groundwater quality monitoring data to discover changes/trends in south flank Tulare Formation groundwater quality over time (Nicholson 1985, Stuart 1987, and Mele 1992c). These efforts were undertaken to evaluate the potential for groundwater degradation to occur from communication between the injection wells and source wells. Elevated concentrations observed in the geochemical analyses would indicate that produced wastewater from injection operations was migrating downdip and affecting source well water quality.

Nicholson's report primarily dealt with groundwater modelling based upon lithologic data from a Section 30R well. Little monitoring data were available from wells 84WS-13B, 82WS-14B and 86WS-18G at that time. The report concluded, based upon a review of the monitoring data, that the data were insufficient to demonstrate communication was occurring between the injection and source wells.

Stuart's report examined monitoring data obtained during the period from January 1986 to July 1987. The data were again taken from source wells 84WS-13B, 82WS-14B, and 86WS-18G. This investigation concluded there was no evidence in the monitoring data of wastewater disposal injection to source well communication.

Mele's investigation examined data obtained during the period from January 1984 to March 1992. The data were taken from wells 82WS-14B, 84WS-13B, 86WS-18G, and 45WS-18G. This investigation concluded the only changes identified in Tulare Formation groundwater quality were 1) a 600 ppm increase over 8 years in chloride ion concentrations in well 86WS-18G, and 2) a higher baseline chloride concentration level at well 45WS-18G than that observed at the other source wells. As discussed by Mitchell (1989), chloride concentration anomalies are not good indicators to demonstrate effects of oilfield wastewater practices on groundwater quality. With no other anomalies in water quality noted, these data are not conclusive.

To compare baseline conditions from when the source wells were first constructed to the present, an additional review of the monitoring data was conducted for this study. This review discovered previously unreported data for the source wells and several pilot wells. TDS concentrations were examined as an indicator that would be readily observed if migration of injected fluids through the formation was occurring. Table 5-1 presents a comparison of TDS concentrations from samples obtained at each of the source wells when they were completed and/or initially tested, and the results of the independent round of samples obtained in 1992. For those wells not active or still in operation as of July 1992, the latest available data are also presented.

As shown by Table 5-1, the values of TDS concentration are clustered primarily in a range from 4,600 to 5,700 ppm. This range in values agrees closely with the findings of the earlier investigations. Higher TDS concentrations occur at north flank well 61WS-8R and at pilot wells 57WS-9G and 48-9G on the south flank. No other increases in value are evident. The reasons for the higher TDS levels at three of the wells is not clear. The data for these wells are limited, and a detailed study of the geology at these locations fell outside the scope of the current investigation.

Some unique water quality information was discovered from pump test data on pilot wells 57WS-9G and 48-9G. These wells were perforated and tested in two zones of the Tulare Formation. Water quality was analyzed from both above and below the Amnicola clay layer in these wells. At well 57WS-9G, TDS concentration was 6,570 ppm above the Amnicola and 11,752 ppm below the Amnicola, a difference of 5,182 ppm (WBEC 1979). At well 48-9G, TDS concentration followed a similar trend; the value was 7,168 ppm above the Amnicola and 11,788 ppm below the Amnicola, a difference of 4,620 ppm (WBEC undated). This sharp increase in value occurred in less than 100 feet of well interval in both wells. The large increase in TDS value over such a short interval illustrates that the Tulare Formation's groundwater is confined to separate zones above and below the Amnicola clay. The water in these two zones is geohydrologically isolated because the Amnicola clay acts as an aquiclude to communication between zones. The water quality data from these wells support Milliken's findings regarding resistivity value changes with depth in the Tulare Formation (Milliken 1992a).

6. Description of Exempted Aquifers and Underground Sources of Drinking Water at Elk Hills

Pursuant to the Section 1425 of the Federal Safe Drinking Water Act, the Environmental Protection Agency (EPA) granted California primacy for the regulation of Class II injection wells in 1983 (40 CFR Part 147 Subpart F). As part of the State Division of Oil and Gas's application for primacy, oil and gas producing aquifers were identified for designation as exempt according to the criteria of 40 CFR 146.04. These designations became final when they were approved by the EPA as part of the state's Underground Injection Control regulatory program.

Figure 6-1 illustrates the location of exempted portions of the Tulare Formation aquifer on and next to the Elk Hills oil field. The boundaries of the exempted portions correspond to the California Division of Oil and Gas's administrative oil field boundaries and thus do not match the civil boundaries of NPR-1 in all areas. In relation to the south flank area, Figure 1-1,

TABLE 5-1 Tulare Formation Source Well Water Quality Data

Well No.	Initial TDS Concentration (ppm) / year		July 1992 TDS Concentration (ppm)
SOUTH FLANK WELLS			
86WS-18G	4,746	1982	5,210
45WS-18G	5,698	1991	5,600
84WS-13B	4,668	1979	not available[1]
284WS-13B	5,744	1990	4,570
82WS-14B	5,732	1980	not available[2]
282WS-14B	5,576	1990	5,100
57WS-9G	6,570; 11,752[3]	1979	not available[2]
48-9G	7,168; 11,788[3]	1978	not available[2]
NORTH FLANK WELLS			
57WS-20S	5,139	1979	not available[2]
61WS-8R	7,009	1987	not available[2]

[1]This well is located adjacent to 284WS-13B and is alternated with the operation of 284WS-13B, thus it was not operational on the day sample were collected. A routine sample from May 1992 had a TDS value of 4,536 ppm.

[2]Well shut-in or abandoned prior to 1992. The latest routine sample for 82WS-14B from February 1989 had a TDS value of 5,600 ppm. The latest sample for 61WS-8R from May 1988 had a TDS value of 8,720 ppm.

[3]These wells were perforated above and below the Amnicola clay layer and separate samples were collected from the two zones during pump testing. The first number is the TDS value above the Amnicola clay layer, the second number is the TDS value from below the Amnicola clay layer.

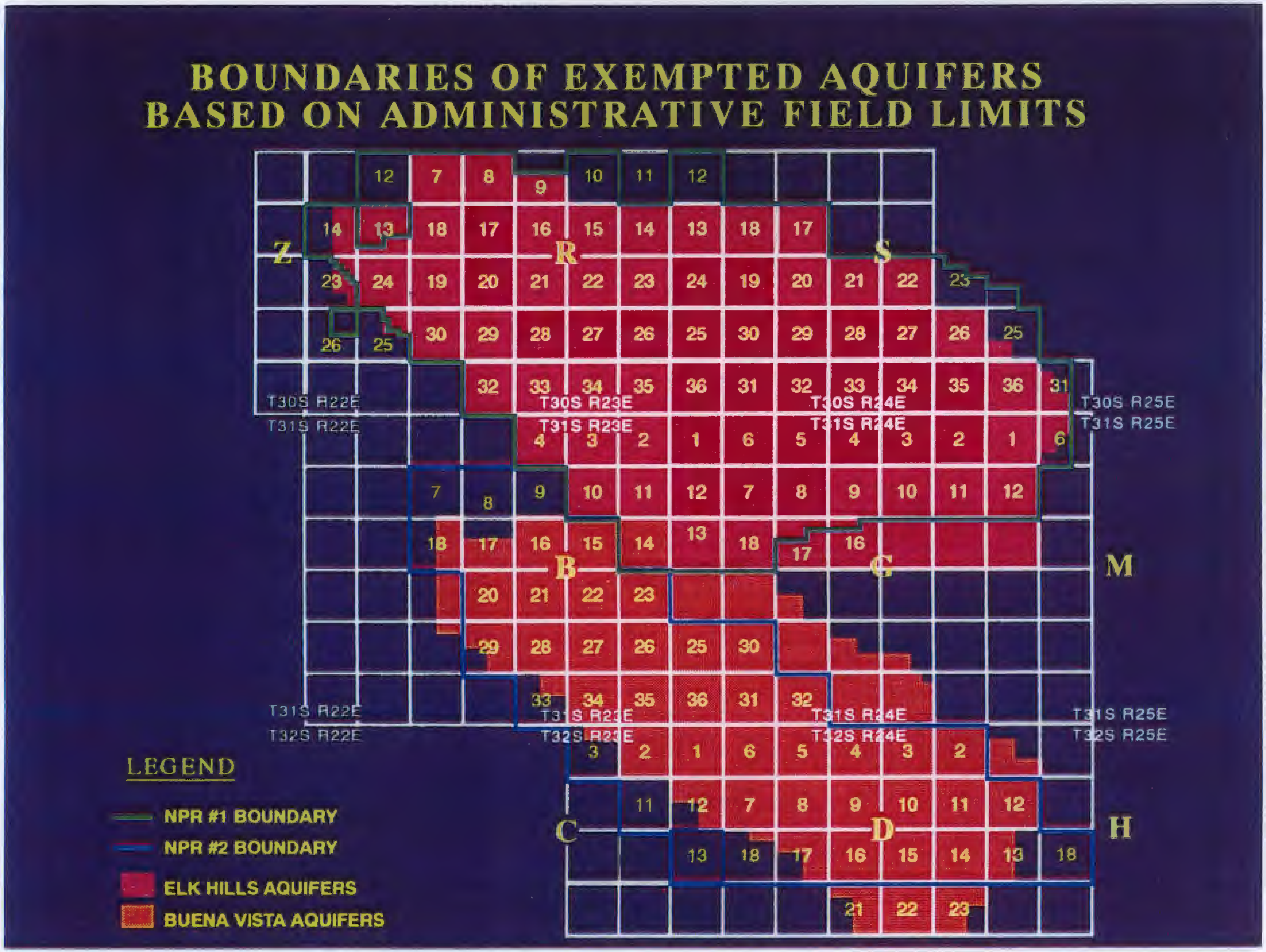

BOUNDARIES OF EXEMPTED AQUIFERS
BASED ON ADMINISTRATIVE FIELD LIMITS
Z
R
S
B
G
M
C
D
H
T30S R22E
T31S R22E
T30S R23E
T31S R23E
T30S R24E
T31S R24E
T30S R25E
T31S R25E
T31S R22E
T32S R22E
T31S R23E
T32S R23E
T31S R24E
T32S R24E
T31S R25E
T32S R25E
LEGEND
NPR #1 BOUNDARY
NPR #2 BOUNDARY
ELK HILLS AQUIFERS
BUENA VISTA AQUIFERS

Figure 6-1

provides a detailed location of the boundaries of non-exempt portions. Specifically, the hatched area shown on the figure is the only portion of the south flank which is not exempt. This area contains groundwater which can be considered as an Underground Source of Drinking Water (USDW) according to the criteria of the Underground Injection Control program (40 CFR Section 146.3). USDW's are afforded special protection under the Safe Drinking Water Act and degradation of USDW quality from injected fluids is strictly prohibited.

From the geochemical analyses of groundwater at pilot wells in Section 9G, it appears that the stratigraphic zone of the Tulare Formation aquifer which lies below the Amnicola clay layer can not be considered as a USDW. This is due to its TDS concentration being greater than 10,000 ppm. Since this zone is within the exempted portion of the Tulare Formation at the Elk Hills oil field, injection of fluids meeting Class II criteria is authorized. In the non-exempted portion of the Tulare Formation outside Elk Hills, in the Buena Vista Valley, this zone would appear to be not subject to the protection measures of USDW's which are provided by the Safe Drinking Water Act. Thus it appears from this limited data set that the only zones of the non-exempted portions of the Tulare Formation subject to USDW protection are the zones above the Amnicola clay. Further investigation of Tulare Formation groundwater quality below the Amnicola clay at other locations may be warranted to confirm TDS content in this zone.

7. Future Direction of the Groundwater Monitoring Program

In accordance with the Final Corrective Action Plan (DOE, 1992b), the groundwater monitoring program which has tracked Tulare Formation groundwater quality at NPR-1's source wells will continue to be implemented as an integral part of the NPR-1 Groundwater Protection Management Program. Standardized source well monitoring procedures have recently been developed as part of this program (BPOI, 1992c). These procedures will be incorporated into the Groundwater Protection Management Program Plan and Groundwater Monitoring Program Plan now under development. In the interim, until these plans are adopted, the standardized procedures will be implemented. Groundwater monitoring will thus be in place as long as injection activities continue. This will provide an effective means of detecting any movement of fluids outside the intended zone of disposal prior to these fluids leaving the boundary of the exempted portions of the Elk Hills Tulare Formation aquifer and entering non-exempted USDW's to the southeast.

8. Conclusions Regarding Observed Effects of Injection on Tulare Formation Groundwater

As demonstrated by previous investigations and this study, evidence of significant changes in the quality of the Tulare Formation's groundwater at Elk Hill's as a result of updip produced wastewater injection has not been observed to date. For example, nearly 10 years of groundwater monitoring has yet to detect a significant change in water quality at well 86WS-18G. This well is located approximately 4,000 feet downdip from the injection well area (see Figure 1-1). Adjacent non-exempt Tulare Formation groundwater is located approximately 1,500 feet downdip to the southeast of this source well. Based on monitoring data and

Milliken's findings on the geology and hydrology of the south flank area, it can be demonstrated that the injected fluids are being confined to the intended zone in conformance with the requirements of the Underground Injection Control program.

The injection of produced wastewater also has not significantly affected downdip exempted groundwater at the other source wells. The stability observed in the water quality data over a long period demonstrates that the injected fluids are diffusing through the Tulare Formation aquifer, as opposed to migrating through the aquifer. The volume for diffusion of injected fluids within the Tulare Formation's aquifer in the zone below the Tulare clay appears to be sufficient to prevent source well water quality degradation. Similarly, because the monitoring data show that there has not been a movement of injected fluids downdip sufficient to degrade source well water quality, it also indicates there has been no movement of fluids into a USDW so as to create a significant risk to the health of persons. Source well groundwater monitoring would have detected any decreases in water quality in advance of any movement of fluids outside the aquifer exemption. The results of this investigation shows that the south flank injection project has been operated substantially in compliance with the requirements of the Underground Injection Control program to protect USDW's.

While there is currently little, if any, produced wastewater injection below the Amnicola clay, it appears that any fluids disposed of in the zone below the Amnicola clay would not be able to move into a USDW. This zone appears to be isolated from the groundwater above the Amnicola clay. An option to consider for future wastewater disposal projects, should monitoring ever indicate a movement of injected fluids toward a USDW, would be to develop other injection wells farther updip. This would reduce the cost to inject fluids below the Amnicola clay.

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